Effects of 10 MeV Proton Irradiation on Electrical Properties of GaAs

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Introduction

Radiation effects on GaAs crystals are less well understood than on Si and Ge. Solid state devices are sometimes employed in the field of ionization radiation. Recent progress in the development of GaAs devices requires further study of radiation effects on this material. The impurity conduction process in GaAs is an important subject to be studied as well as the usual conduction band conduction process because of the difficulty of material purification at present and then high impurity concentration in device material put to practical use.

This paper is concerned with proton irradiation effects on electrical properties of n-type GaAs single crystals. It has been investigated that the proton induced defects acting as acceptors play an important role in conduction process and an activation energy ε_3 of the hopping conduction process varies with changing impurity compensation.

Experimental Results and Discussion

Hall effect measurement were made with a conventional dc method at temperatures between 10 and 300 K for three samples T21-02, G11-03, and G3n-01 having different concentrations $n=1.6\times10^{18}$, 1.3×10^{17}, and 2.6×10^{16} cm^{-3} at 300 K, respectively. Before irradiation the temperature dependence of the electrical properties indicates that the conduction due to the impurity conduction process is significant in all the samples. Especially the sample with the highest carrier concentration (T21-02) shows almost completely constant resistivity in the whole temperature range, namely, the metallic impurity conduction occurs. The hopping type conduction with an activation energy ε_3 is observed at low temperature region in the sample G3n-01. Irradiation was carried out at room temperature by 10 MeV protons from a cyclotron of The Institute of Physical and Chemical Research.

With irradiation the carrier concentration n and the carrier mobility μ decreased, and then the electric resistivity ρ increased. The carrier removal rate, $-dn/d\phi$, was much larger than that of high energy electron irradiation.1) The decrease in carrier concentration suggests the increase in number of acceptor-type defects. The change in n with irradiation is listed in Table 1.

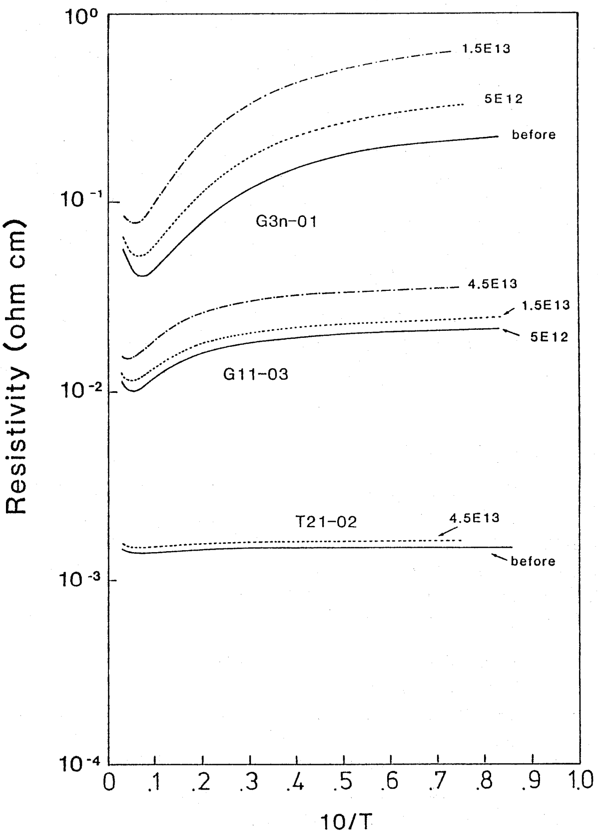
Carrier concentration of p-type GaAs also decreased by 10 MeV proton irradiation,2) which suggests that donor-type defects are also produced. The facts indicate the creation of both the donor-type and acceptor-type defects by proton irradiation. Different type defects are active in different type (n or p) samples. This is due to the position of the Fermi level in the forbidden band. In high conductive n-type samples the Fermi level is close to the bottom of the conduction band and all acceptor-type defects except the defects whose energy levels lie above the Fermi level are active and capture the conduction electrons, while most donor-type defects except very shallow donors are inactive.

Magnitude of the carrier mobility gives valuable information on the concentration of charged centers. It is clear that the change in mobility at 300 K is resulted from a change in concentration of charged scattering centers by irradiation. From the analysis of the mobility data charged donor concentration N_d^+ and acceptor concentration N_a^- were calculated.3) It became evident from the calculation that the decrease in n with irradiation was due to a larger increase in acceptor concentration than an increase in acting donor concentration.

Table 1. Change in n (cm^{-3}) at 300 K with irradiation

Sample \ Fluence ($protons/cm^2$)	0	$5x10^{12}$	$1.5x10^{13}$	$4.5x10^{13}$
T21-02	$1.61x10^{18}$	-----	-----	$1.46x10^{18}$
G11-03	-----	$1.28x10^{17}$	$1.12x10^{17}$	$1.29x10^{17}$
G3n-01	$2.58x10^{16}$	$2.07x10^{16}$	$1.67x10^{16}$	-----

Figure 1 shows the temperature dependence curves of electric resistivity ρ before and after irradiation for each sample. The resistivity of all the samples increased in whole temperature range with irradiation. In the sample G3n-01 two activation processes of impurity conduction were observed: the hopping conduction with an activation energy ε_3 and another type of impurity conduction with ε_2 which appears characteristically in the intermediate impurity concentration samples. ε_3 increased slightly with irradiation. It is deduced that the increase in ρ of G3n-01 and G11-03 arises from a decrease in donor site electrons because of the increase in compensation. When the compensation increases, the random potential becomes greater and the mobility edge may be shifted upwards and then ε_3 increases.4) The increase in ρ of T21-02 possibly reflects a decrease in number of electrons in the impurity band.



References

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